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Mapping the interactions that drive the collective motion of soccer players during gameplay

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Abstract: The coordinated movements of soccer players during a game bear a remarkable resemblance to the flocking, schooling, and swarming formations found in nature. These patterns emerge from the complex interactions between individual players, the game's constraints, and the physical limitations of the players and their environment. The result is a self-organizing system where emergent motion is driven by constant adaptations among individuals in response to competitive pressures. In this study, we use the force-mapping approach, a technique that is commonly applied to animal collectives, to investigate the spatial interactions between individual players and environmental elements such as the field boundary. This method has been extensively detailed in previous studies (Mudaliar and Schaerf, 2020) and provides a representation for how individuals adjust their motion based upon the relative position of neighbouring teammates. We analysed changes in speed and direction of motion for all possible pairs of players at each time step, breaking them down into component form. Through this analysis, we inferred the interaction rules that govern collective motion in response to the relative position of teammates. Our aim was to identify the presence of rules similar to those used in theoretical self-propelled particle models, such as repulsion, alignment and attraction that can be used a basis to simulate player motion. The analysis was further extended to include the distributions of descriptive statistics covering interpersonal distances (by topological rank), distances between players and the formation centroid at each time point and maximum size of playing formation in the cross-field and down-field directions. This provides an understanding of the link between player interactions and the emergent properties of the formations.

Our findings reveal that players exhibit attraction-repulsion interactions to maintain desired interpersonal spacing. Our results build on previous research by demonstrating the balance of a short-range repulsion force and a long-range attraction force between players that give rise to formations and collective movement patterns observed. We found that this balance is maintained by individual players making adjustments to both their speed and direction. The short-range repulsive force is critical for maintaining field coverage and the long-range attraction force allows players to maintain cohesion within their formations and facilitate effective group movement on the field. During the defensive gameplay, players maintain a tighter distribution of desired distances and more compact formations, with players spacing themselves closer for a given rank compared to the distances observed in attacking gameplay. When competitive pressures are removed in the out-of-play phase, only the attraction force is evident, and the repulsion-attraction balance is no longer observed. A repulsion interaction is also observed between players and the field boundaries, indicating that players maintain a desired spacing with the edge of the pitch. Closer analysis of player movement also demonstrated that the player's relative locations to one-another are more important than their orientations (relative direction of movement) in determining changes in motion. Similar patterns, although at different spatial scales, have also been observed in groups of animals (Katz et al., 2011). Short-range repulsion, long-range attraction, and alignment interactions have been observed in the movement of fish, birds, and insects. These findings suggest that while the motivations and biological processes are different, there are common mechanisms underlying individual interactions within collective movements among both humans and animals.

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